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Computer-Aided Information Systems for Gaming

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ADVANCED RESEARCH DIVISION
TECHNICAL PAPER RAC-TP-133
Published September 1964

Computer-Aided Information Systems for Gaming

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with
Guide to the Literature
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FOREWORD

This paper has been prepared as an invited chapter of a forthcoming book, Fundamentals of Information System Science and Engineering. The book is sponsored by the MITRE Corporation and is to be published by the McGraw-Hill Book Company. The other chapters are mainly concerned with computer-aided information systems for different purposes. The book is intended for use by someone with at least a bachelor's degree in engineering or its equivalent and 3 years of mathematics who might use the book as a hypothetical first-year graduate course in information system science and engineering. Thus the paper is largely expository.

The paper should be of interest to the Army in its own right aside from its appearance as a chapter in the book. Accordingly it is distributed separately to interested Army agencies at this time.

The paper has been cleared for publication in the open literature by the Directorate for Security Review (OASD-PA), Department of Defense and by the Chief of Research and Development, US Army.

The author wishes to express his appreciation to Lt Col Ralph W. Lang, USA, Chairman, and to the other members of the Project Advisory Group for RAC Study RS-305 under whose auspices the paper was prepared. He also wishes to thank his colleagues at RAC who offered information, criticism, and advice—particularly the late Dr. Lynn H. Rumbaugh, Mr. John L. Donaldson, Mr. Richard G. Williams, Miss Arla E. Weinert, Mr. Richard M. Lester, Dr. John W. Brackett, and Mr. Raymond P. Wishner.

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Computer-Aided Information Systems for Gaming

ABSTRACT

Scientific war games have been under development by military operations research groups since about 1960 and business games by industrial operations research groups since 1956. From an information system point of view these games may be divided into three types—computer simulations, digital man-machine games, and continuous variable man-machine games. Computer simulations, or completely automated games, are always rigid, usually stochastic, and generally very detailed. Since they are not limited by the decision-making speed of human beings, they may be executed rapidly, permitting repeated plays with large-scale variations of input conditions and chance factors. Digital man-machine games, or partly mechanized games, employ digital computers for bookkeeping, computing, and transmission of data but use people for decision making. In digital man-machine games both speed of execution and level of detail are sacrificed in the interests of obtaining the flexibility of human participation. Continuous variable man-machine games employ people for decision making and electronic analog computers for computation. The human decisions are introduced continuously as the game proceeds rather than periodically.

Special developments in gaming include the use of systems of games with outputs of one employed as inputs of another, the use of heuristic problem-solving techniques in games, and the development of specialized computer hardware and software for gaming purposes.

Finally, note that although gaming is accepted as a useful tool for many purposes its employment in some of its roles is controversial.

INTRODUCTION

In normal usage the term "game" covers a variety of activities. For the purpose of this chapter these activities will be restricted by three conditions.

First, the game must be a model of a real-world activity. This restriction excludes abstract games for amusement or gambling, such as card games or games of dice. Some parlor games have a recognizable real-world connection. Chess, for example, by straining the imagination, can be regarded as a model of warfare. We will not quibble about this point but will arbitrarily exclude parlor games played for the entertainment of the participants. Games dealing with the real world rather than with abstract activities are sometimes called "operational games."

Second, the real-world activity that the game represents must involve competition among people or groups of people. Models of military and economic activity, such as military combat operations and multicompany business operations, qualify under this restriction. Recently several political games have been developed that might also be included. On the other hand, models of unopposed military support operations and noncompetitive business activities are generally excluded since the element of competition is lacking.

Third, the game must be a conceptual rather than a physical model. This restriction rules out war games played on actual terrain with actual troops, two-sided naval maneuvers, football games, other athletic contests, etc. The term "paper game" is sometimes used to distinguish conceptual games from the physical variety.

An activity satisfying these three conditions is frequently referred to as a "simulation," and the word "game" is reserved for activities that, in addition, satisfy a fourth condition: the participation of human players, or role-playing. As interpreted in this chapter, "gaming" will cover both types of activities. In order to distinguish between them they will be referred to as "computer simulations" and "player games" respectively, and the word "game" will be used as a generic term to cover both.

Unfortunately the terminology employed in gaming is confusing. Much of the confusion is associated with multiple uses of the words "game" and "simulation." According to Webster, "simulation" is the act of assuming the appearance without the reality. In popular use the term is generally confined to the representation of one dynamic activity by another. For example, a topographic map is not generally referred to as a "simulation of terrain" since both the terrain and the map are static. On the other hand the representation of a dice game by a series of drawings of random numbers is called a "simulation" since the time, or at least the order of events, is preserved. Simulation is sometimes used in the specialized sense of representation by an item of hardware or machinery. For example, an analog computer may be used to

"simulate" the aerodynamic environment of a prototype missile under test. This use of the term will cause no confusion since it refers to a physical rather than a conceptual model. Furthermore the element of competition is lacking. More to the point, however, a digital computer may be used to simulate a two-sided competitive military engagement. Some people use the word "game" for what we have called a computer simulation; others use the term "simulation" for what we have called a player game; and still others use the terms "game" and "simulation" interchangeably. People reading the literature of gaming will have to interpret the terminology in context.

Player games, even those representing complex activities involving many people, seldom employ more than a few players. In the real world a division-sized military engagement may involve up to 20,000 people on a side, all of whom make decisions affecting the outcome of the engagement. The individual soldier decides what bush to hide behind when he takes cover and precisely where to aim his fire. Similarly, decisions are made at all intermediate echelons up to the division commander, who decides on major tactics and strategies. A division-level player game on the other hand, usually involves only a commander and a small staff on each side. These players generally wear several hats and make not only the division commander's major decisions but also those for several levels down—perhaps through battalion. Major decisions below this level and all minor decisions are made automatically according to a standard doctrine aggregated into the rules of the game. Similarly in business games the participants do not generally make detailed decisions on minor points. Thus even in games with player participation, only a few of the higher-level real-world decisions are made by the players. The computer simulation may be regarded as the limiting case of a player game in which the degree of player participation has decreased to zero.

Humans also participate in player games in another way—as referees, umpires, or, to use the currently preferred term, "controllers." A controller may function as an individual or as part of a control team. The controller's duties vary from one game to another. In games in which the rules are completely spelled out, his functions are generally to instruct transient players in the mechanics of the game and to serve as an interpreter of the rules when required. In other games he assesses all or part of the game by judgment in lieu of rules and formulas. In this case he is more likely to be called an umpire. Sometimes he uses judgment only to override rigid rules when they appear deficient. In either event he usually is responsible for the administration of the nonmechanized portions of the computing, bookkeeping, communications, and other information-handling processes.

War games[1] have been used by military organizations for many years for both training personnel and testing plans. They reached a high state of development in the Prussian Army in the mid-nineteenth century and were used extensively by both the Germans and the Japanese prior to WWII.

War gaming as a technique of scientific analysis has been under development in this country by military operations research groups since about 1950. These groups were the first to apply computers to games and to develop computer simulations of military operations. In their roles as military research tools, war games and simulations have been used by all military services and have been employed to study problems at all levels from small-unit tactical

actions to world wars. Specifically they have been used to evaluate weapons systems, tactics, strategies, and organizational concepts; to develop doctrine; and to choose from among competing budget allocations.

The first business game was developed in this country for the American Management Association in 1956. Since that time more than 100 management games have been devised both in the US and abroad. These games have generally been used for executive training. However, they are beginning to be considered for testing plans and for research in business in much the same way that war games have been used for testing plans and for research in military subjects.

Gaming involves the playing through of a model, either with human participants or without. It should not be confused with the mathematical theory of games that considers games from a more abstract point of view. This theory[2] regards a game as a conceptual mathematical problem and seeks a mathematical solution to it. It considers the solution of a game to be a description of the best sequences of moves of the players and a specification of the players' returns. In the theory, games are classified as non-zero-sum or zero-sum according to whether or not there is a net change in the total assets of all the players at the end of the game. The mathematical theory of games is responsible for the notion of a minimax strategy whereby each player in a zero-sum two-person game seeks to minimize the maximum damage that his opponent can do to him. It is also responsible for the concept of a mixed strategy or another according to random selection with precalculated odds. The theory has been developed to the point where some simple types of games may be completely solved mathematically. The mathematical theory of games is not capable of providing numerical solutions for most operational games of practical interest; however, it can give insight into the theoretical nature of the solution and provide some guidance for players. It will not be considered further here.

Certain terms, some borrowed from the mathematical theory of games, are in more or less general use. Games are classified according to the number of playing teams as two-person games, three-person games, etc., regardless of the number of people on the teams. A game is governed by rules that define the permissible moves of the players. Strictly speaking the set of rules is the game, and the act of executing the rules is a play of the game. However, the terminology is very loose and "game" is frequently used for "play." If the rules are completely spelled out in advance the game is rigid; if the rules are determined on a makeshift basis as the game proceeds, it is free. The difference between rigid and free is not whether human judgment is employed. Judgment is always involved in model making. It is simply a question of whether the rules are constructed in advance or formulated as the occasion arises. Most player games fall somewhere between the completely free and completely rigid varieties and hence may be referred to appropriately as semirigid. The term "analytic" is sometimes used to describe a game whose rules are to the maximum extent practicable based on established scientific facts rather than on the subjective judgments of experts in the field. If all teams have access to all information, the game is open; if some information is withheld from players, the game is closed. Closed games are used to simulate the acquisition of military intelligence in war games and the security of proprietary

information in management games. If one or more of the players is constrained to follow a particular sequence of moves selected in advance, the game is a set-piece game; otherwise it is a free-play game. Set-piece games are used to examine specific strategies. Games are frequently stochastic, using the selection of random numbers to represent chance events. Following the terminology employed in numerical analysis,[2] they are sometimes called "Monte Carlo games" or "Monte Carlo simulations," as the case may be. Player games employing computers are referred to as "computer-assisted games" or "man-machine games."

Games cannot be developed overnight. Some of the more complex ones have required many man-years of work. First there is the problem of constructing a model of appropriate scope and level. The game must contain enough detail to be realistic and at the same time be sufficiently aggregated to be playable. Usually after the design of the game is completed a series of trial plays is required both to achieve the appropriate balance between detail and aggregation and to eliminate errors. Then there is the problem of obtaining data. Available figures are usually neither sufficient nor suitable. Furthermore they seldom cover all the items needed. A basic difficulty is that quantitative numerical data are required for items that are normally treated only qualitatively. Finally it is necessary to verify that the game does in fact approximate reality sufficiently closely for the purpose to which it is put. This is difficult even for a current operation. For future operations one verifies as best he can by means of historical precedents, equipment design specifications, field experiments, and, as a last resort, informed judgment.

Gaming has had its best results, at least for research purposes, when used in conjunction with other techniques. Thus gaming may generally be supplemented advantageously by historical surveys, field experiments, or analytic studies.

Most games have been developed to help solve specific problems or satisfy immediate needs. Therefore a considerable body of experience in the practice of gaming exists, but little theory. Accordingly this paper is devoted more to specific games than to general principles. Examples will be divided into man-machine games and computer simulations according to whether or not there is player participation. Man-machine games will be further divided according to the type of computer—digital or analog. Thus specific games will be treated under the headings "Computer Simulations," "Digital Man-Machine Games," and "Continuous Variable Man-Machine Games." Topics not included under specific types of games will be covered in the final section "Other Topics."

Computers have been used more extensively in war games than in business games. Accordingly war games will be emphasized. Of necessity most of the examples will be taken from the games with which the author is most familiar—those developed by RAC and its predecessor the Operations Research Office.

COMPUTER SIMULATIONS

At one extreme on the spectrum of mechanized games is the completely automated game or computer simulation. It is usually performed on a digital computer. By some definitions it is not called a game since people do not participate in it during the course of play.

Computer simulations are of course always rigid in the sense that the rules are spelled out in advance. Otherwise they could not be mechanized. They are usually stochastic. In military simulations, engagements are generally broken down to the level of elementary pieces such as individual weapons, vehicles, aircraft, and missiles. In the management area they are usually confined to specialized fields such as production scheduling, traffic control, and inventory management—processes in which the competitive element does not enter directly. Simulations are not limited by the decision-making speed of human beings and hence once set up may be executed rapidly. This permits repeated plays with large-scale variations of input conditions and chance factors.

There are two basic methods of sequencing a computer simulation. The first is time sequencing. All variables are periodically updated at the same instant of game time. The intervals are generally of equal length for any particular simulation but vary from fractions of seconds to hours from one simulation to another. The exact time of an event is not specified—only the time interval in which it occurs. A simulation time sequenced in this manner is of course limited as to the precision of time resolution by the length of time interval. Furthermore it is frequently inefficient in that calculations continue at the same rate during time periods when nothing of interest is happening.

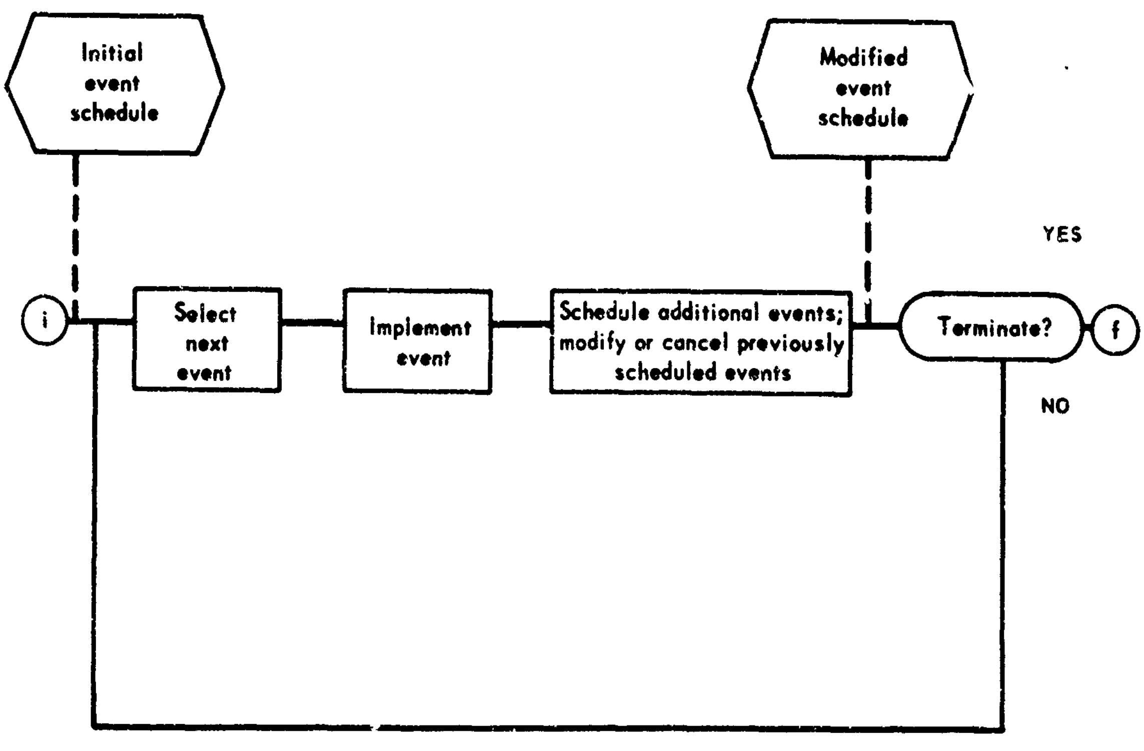

Fig. 1—Event-Sequenced Computer Simulation

The other method is event sequencing. Here the variables are changed one at a time so that the simulation takes place on an event-by-event basis. The organization is as shown in Fig. 1. An initial schedule of events is given among the initial conditions. These events are sorted according to increasing

time of occurrence. During each cycle the computer selects and implements the next event from the event schedule. As a result of this event it may schedule additional events or modify or cancel previously scheduled events. These changes are merged into the event schedule according to time of occurrence to produce a modified event schedule. The sequence is repeated until the simulation is terminated.

An event-sequenced simulation is not limited in resolution by the length of the time interval. Moreover it does not waste time in updating variables during periods of inactivity. However, difficulty is encountered when an event-sequenced simulation exceeds the high-speed memory of the computer since the order in which the additional program and data will be required from the secondary memory cannot be predicted in advance. Some simulations use a combination of the two methods.

Computer simulations require large quantities of input and can produce large quantities of output. Auxiliary programs to edit and summarize the data are sometimes longer than the program for the simulation proper.

CARMONETTE

As an example of an event-sequenced digital simulation we will describe CARMONETTE[4-6]—a two-sided small-unit combined-arms ground-combat simulation that has been under development and in use at RAC for a number of years. CARMONETTE simulates a company-sized engagement. Its purpose is to evaluate proposed small-unit weapons systems in a tactical environment. The pieces with which CARMONETTE deals are tanks, vehicles, infantry squads, etc. These pieces are described in sufficient detail so that the inputs to the simulation can be measured experimentally. Any specific terrain may be used. Thus CARMONETTE is capable of handling a variety of problems concerning different weapons systems, tactics, and doctrines on different terrains. So far its use has been restricted to the evaluation of specific weapons systems on the terrain of the Hunter Liggett Military Reservation used by the US Army Combat Developments Command Experimentation Center.

CARMONETTE can handle up to 36 units on a side. These units are generally vehicles or infantry squads. The units may be of four different types distinguished from each other by their composition, capabilities, and vulnerabilities. Up to nine different weapon types may be given to each side and up to four of these may be assigned to each unit. Weapons are characterized by their ranges, rates of fire, and kill probabilities against various units. All tables of organization and equipment must be broken down into such units.

Variables describing the units are kept current throughout the play. The more frequently used variables are contained in 300 words of core storage. Into these words are densely packed such information as location, posture, type, and firing status of all units. The core-stored information is supplemented by approximately 2500 words of unit information tables stored on a magnetic drum. The unit information tables contain less frequently used information describing the units: individual intelligence, condition, firing status, mission, etc.

The terrain is partitioned into a 36 by 36 set of grid squares (recently expanded to 36 by 64). These squares are arbitrary in size but are usually selected to be 100 meters on a side and hence the 1296 squares cover an area

about 2 miles square. The terrain in each grid square is described by both nondirectional and directional terrain features. Nondirectional features include items such as elevation, height of vegetation or surface irregularities, concealment from enemy ground observation, cover from enemy fire, trafficability, natural features, and artificial features. Vector features include the existence and condition of roads. The descriptions of these features are densely packed in about 2000 words of core memory. Other environmental data such as weather and time of day are held constant over the time of play and are only included implicitly. For example, visibility is reflected in moving speeds and intelligence-acquisition capabilities and the effects of precipitation are reflected in ground-trafficability conditions.

At the beginning of the simulation the computer is given the initial positions of all forces and a tactical scenario spelling out missions, objectives, target priorities, moving and firing doctrines, etc., on a unit-by-unit basis. In carrying out its mission each unit performs such activities as target selection, firing, movement, communication, and acquisition of intelligence. In target selection a unit lists all targets compatible with the range of its weapons and intelligence. It selects from among these targets on the basis of zone and priority as spelled out in the scenario. The actual firing consists of applying hit and kill probabilities and modifying the unit records to reflect the residual condition of forces, ammunition on hand, and intelligence status. In the movement selection each unit considers whether it should move and, if so, to which of the eight adjacent terrain squares. The movement selection process is stochastic with the probability of moving to a particular square given by a criterion function based on the mission, vulnerability, and available targets. In some plays the stochastic element of movement is bypassed and the movement of pieces controlled entirely by the scenario. Provisions are made for communications between forward observers and indirect fire units and between remote controllers and their guided missiles. Intelligence is simulated by tables recording each unit's knowledge of the locations and types of enemy units. The entries of these tables are modified when a unit reveals its position by firing, when a visual sighting is made, or when the presence of an enemy unit is noted by a forward observer. Terrain profiles are computed for the determination of visual sightings. The simulation is terminated at a predetermined time or according to a predefined criterion based on a specified level of casualties.

A separate computer run produces detailed edited outputs and it is hoped to add a routine to produce summary statistical tables.

It is planned to add an intervention system whereby additional data may be introduced during the course of a play. At a predetermined game time the computer will be directed to interrupt the simulation and read out the condition of the battlefield for human consideration. When again directed it will read back in the battlefield conditions as modified by human intervention. This feature will permit human decisions to supplement the tactical doctrine given in the scenario. Alternatively the simulation could be interrupted at some particular game time and elements that are normally held constant changed automatically. This feature would permit prescheduled variation of normally fixed environmental factors. Both features will permit the introduction of special major events such as the effects of a nuclear weapon on the battlefield.

CARMONETTE is programmed for the Univac Scientific Computer. The program, exclusive of the editing and analysis routines, contains about 8000 two-address instructions and 40,000 to 50,000 data items packed into another 8000 words. About 2500 words describe the current state of the system, 2000 are used for the constant terrain description, and 3500 or so are devoted to special tables used throughout the calculation. The frequent reference to 36 is related to the number of bits per word in the computer. Much of the data is stored in terms of bit maps. The 36 by 36 terrain compartments are mapped on the 36 bit positions of each of 36 consecutive words in the computer memory. The presence of a particular binary terrain characteristic in a grid square is then represented by a bit in the corresponding bit position. Similarly the characteristics of the various units are described on a bit-by-bit basis. There are five clocks for each unit, four representing the unit's weapons and one its movement and posture. Initially these clocks are arbitrarily set to small values and reset by subsequent events as the simulation proceeds. Many of the clock settings are subject to random variations. In a recent set of plays an average of 25 min of computer time was used to simulate 12 min of battlefield time—a real-time-to-game-time ratio of about 2 to 1. The output edit and analysis is a separate process and requires about 30 min per play.

The CARMONETTE code is currently being rewritten for an IBM 7040 computer.

Air-Battle Model

Another large-scale computer simulation of military combat operations is the US Air Force Air-Battle Model. This simulation was first developed in the mid-1950's and has undergone considerable evolution since that time. An intermediate version[7] is described here.

The simulation treats a two-sided global air war. In contrast to CARMONETTE it is time sequenced rather than event sequenced. It is designed for the study of problems associated with such topics as missile and manned bomber mixes and deployments, base hardening, aircraft dispersal and evacuation policies, weapon stockpile configurations, the use of decoys and other aids to penetration, the selection of aircraft routes, and target-bombing systems.

The Air-Battle-Model System consists of three parts: the Plan Converter, the Air-Battle Model proper, and the Output Programs. The Plan Converter transforms tabular input in air force terminology to initial conditions and in-flight plans for input to the computer. It constructs plane and tanker lists that identify plane types, the bases at which the planes will locate, and the time at which planes are available for missions. Planned sorties for these planes are checked for consistency so far as distance, time, and fuel are concerned. Planes flying approximately the same path at the same time are aggregated into cells. A target list is constructed and sorted by area. Initial and in-flight aircraft plans, missile plans, and tanker plans are sorted by time and place and edited into blocks of data acceptable to the simulation proper.

The Air-Battle Model proper consists of a master control routine and a set of detailed routines simulating major operational activities. The routines launch bombers and trace them through a series of events such as refueling,

detection by enemy radar, attack by surface-to-air missiles and interceptors, application of penetration aids, return of defensive fire, adoption of an evasive course, release of bombs, return to base, and recovery. The launching of missiles and tankers is simulated, and attrition by enemy defenses is computed. Target selection and reconnaissance are represented. Blast and radiation effects are computed. These operations are executed each time period as appropriate, first for one side then for the other. In this way the simulation is continued, interval by interval, until terminated.

The output programs sort, compile, and tabulate the detailed histories of all offensive and defensive bases and all operations. The information generated is cataloged in a tape library for future reference. A variety of print-outs of detailed and aggregated results are produced as desired by the user.

The simulation was programmed for an IBM 709 computer using the CL-I programming system—a system designed to facilitate the initial programming and modification of large complex logical problems containing masses of indefinite poorly defined input data. The Plan Convertor contained 15,000 instructions; the simulation proper 25,000. The simulation would handle up to 25,000 planes, 3000 in-flight planes per time interval, 1000 offensive bases, 1500 local defense installations, 1500 radars, 3500 targets, 1400 ground zeros per time interval, 31 bomb types, and 32 plane types. Each time interval covered 15 min, and the ratio of real time to game time was approximately 1 to 1.

Recently the Air-Battle Model has been modified and expanded under the new name of STAGE (Simulation of Total Atomic Global Exchange).[8] The strict interval-by-interval time sequencing formerly employed has been changed to a mixture of time and event sequencing. A new major component has been added, the Sortie Programmer, whose function is to prepare sortie specifications from outline plans and data tables. A new control system has been devised permitting input and reference data to be changed easily and submodels to be inserted, deleted, or altered without changing the executive control or other submodels. The new version is programmed for the IBM 7090 and requires about 160,000 machine instructions.

Other Computer Simulations

Many computer simulations of military combat operations have been constructed. A number of these have been simulations of relatively simple operations such as fighter-bomber duels. However, others have been simulations of large complex military operations. Computer simulations have been used extensively for the study of air defense problems. They are employed in this role by all three of the US military services as well as by some European nations.[9] In addition all three services employ simulation extensively for other types of military combat operations peculiar to the service concerned.[10] Noncombat military operations have also received attention. For example, one of the Operations Research Office (ORO) simulations dealt with the march of a battalion-sized armored formation.[11,12] The problem was concerned with searching for ways of extending vehicle operating range. The simulation considered constraints due to operating schedule and breakdowns. Spare parts, tools, mechanics, rules of march, repair doctrines, and communications within the unit were included in computing the effect of maintenance activities.

It is difficult to estimate quantitatively the extent to which computer simulations have been used. Applications to large-scale military combat situations number at least in the dozens. And, of course, digital computer simulations have been applied to hundreds of noncompetitive situations beyond the scope of this chapter.

DIGITAL MAN-MACHINE GAMES

At the other extreme on the spectrum of mechanized games is the completely manual game. In comparison with a computer simulation a manual game is slow since it is limited by the speed at which human beings can think and calculate. Hence in a manual game there can be few repetitions of play and no wholesale variation of inputs and chance factors as is done in a computer simulation. However, manual games can be used in situations where the rules are not all specified in advance, some of the decisions being made instead by the game participants as the play proceeds. This gives the manual game a somewhat broader range of applicability and more flexibility than the computer simulation. A manual game provides an orderly method of combining the scientific knowledge and judgment of experts in diverse fields; it ensures that a competitive situation will be considered from both sides; and it capitalizes on the ingenuity of human participants. Manual games are also useful for training because of the element of human participation. At this point purely manual games are dismissed, important though they may be, as beyond the scope of a paper on computer-aided information systems.

Between the extremes of the manual game and the computer simulation is a range of partly mechanized man-machine games. Such games are developed in an attempt to realize insofar as possible the advantages of both the manual game and the computer simulation. During the play of a game four functions must be performed: decision-making, computing, bookkeeping, and transmission of data including display of results. Man-machine games generally aim at mechanizing the last three of these. Rather elaborate physical equipment including communications systems, control consoles, and display devices is sometimes used to facilitate the communication between man and machine.

Man-machine games will of course never achieve the extreme speeds that are obtained in computer simulations since the mechanized operations must wait for human decisions. However, an appreciable savings in time can be realized over a manual game by eliminating some of the human delays. Furthermore much more detailed models may be employed. Such a game also provides for more uniform and objective refereeing than a completely manual one. It permits automatic recording of intermediate and final results and frees human participants to concentrate on the substance of the game rather than the mechanics of rules and formulas.

By far the greater number of man-machine games employ discrete variable models and use general-purpose digital computers. The most common way of sequencing such a game is to partition the time span into discrete time intervals and to perform the required operations in cycles. The time invervals may be of equal length such as a day in a war game or a calendar quarter in a business game, or they may be adjusted to encompass specific events. For want of

a better term the terminology of computer simulations is followed, and a game organized in this manner is called a "time-sequenced man-machine game."

The major cycle of events of such a game is shown in Fig. 2. The players are given the initial state of the game and the environment. The cycle is divided into two subcycles—a decision cycle and a computation cycle. During the decision cycle the players make their decisions based on the current state of the game. During the computation cycle the machine computes a new state based on the current state, the player decisions, and chance. This sequence of events is repeated again and again. The play terminates after a predetermined number of cycles, according to predetermined values of the state variables, or on an arbitrary order by the controller.

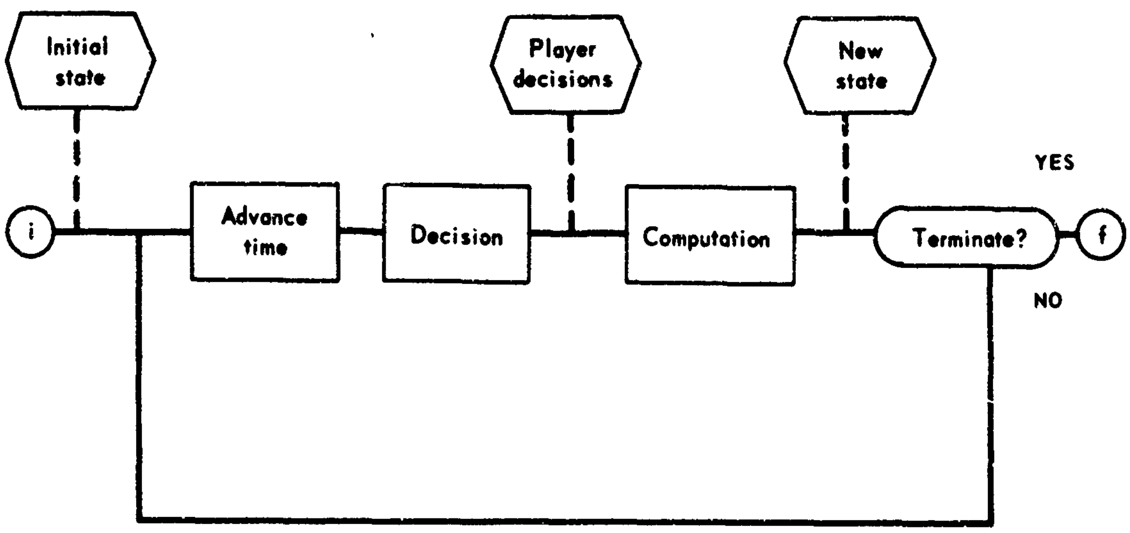

Fig. 2—Time-Sequenced Digital Man-Machine Game

The computer is usually used off-line. This permits flexibility in scheduling. Moreover it is economical since the computer can perform other tasks during the decision cycles. Input to the computer is usually on punch cards and output on a line printer. Thus any computer of sufficient capacity may be used for the task. The system is adaptable to handling large quantities of data, to carrying out extensive calculations, to keeping detailed records, and to producing neatly edited tabular results. It is in use on many digital computer-assisted games.

THEATERSPIEL

THEATERSPIEL[13] is a theater-level war game developed by RAC for the study of Army problems. Although the emphasis is on Army ground-combat operations, the game includes theater air and air defense operations as well as logistics. It is used to aid in the determination of tactics, strategies, deployments, logistic requirements, doctrines, etc., at the theater level for each of several theaters of operations. Senior retired military officers serve as force

commanders and control personnel. The game is an outgrowth of a long series of theater-level war-gaming efforts at RAC and ORO. As of this writing seven plays have been conducted in the game's present form.

In terms of definitions introduced earlier, the game is closed, semi-rigid, analytic, and free play. All the bookkeeping and most of the assessment procedures are mechanized. Decision making on the theater commander's level and the unmechanized assessment procedures are conducted manually. Forces are handled in discrete units and are generally resolved to the level of division for ground-combat forces, and to wing for aircraft, battery for surface-to-air missiles, and depot for supply points. Input from the human participants to the computer is effected by punched cards, and output is recorded by a high-speed line printer. The game is time sequenced as in Fig. 2 with time units that generally represent 1 day of game time.

The entire play, particularly the initial moves, is conducted against a background of political, economic, and cultural factors not expressed in sufficiently quantitative terms to permit introduction in the game proper. These factors together with a list of forces available, weapons capabilities, environmental conditions, and player's objectives, are given in the scenario for the play. The scenario has separately bound red and blue annexes containing intelligence information that is to be released to only one of the playing teams.

At the beginning of play the players have available, in addition to the scenario, a computer listing of the initial state of all units called the "status-of-forces file" and a 1:500,000 topographic map of the area of operations. Each team has plotted on its map the positions of its own forces and an estimate of the positions of the enemy's forces. During each decision cycle the players generate orders to the units under their control taking account of their prescribed objectives and the current state of the game. Orders cover such activities as movement, posture, target designation, etc.

The control team integrates the orders of the two playing teams and judges their relative feasibility. Specifically the control team considers whether forces can execute their orders without exposing themselves to enemy action, whether a move is logistically feasible, and what interactions or engagements will occur when one team's orders are superposed on the other's. The control team translates a description of these interactions into appropriate code for punching into cards and feeding to the machine. The control team also introduces externally imposed events such as reinforcements from outside the theater or actions on the part of neutrals or allies.

During each computation cycle the computer accepts the interaction data from cards, matches the forces engaged with their descriptions in a status-of-forces file, and performs the interaction assessments. The assessments are calculated according to four models: an air model, a support-weapons model, a ground-combat model, and a logistics model. The computer uses the results of the assessments together with the external events introduced by the control team to update the status-of-forces file. Finally the computer points out a new edited status-of-forces file and an edited and annotated casualty-assessment form.

The play is terminated after a predetermined number of days or on the occurrence of some event, such as overrunning a specified piece of territory, or on an arbitrary order by the controller.

Finally a postplay analysis is conducted. This usually takes the form of an open critique in which the players attempt to interpret the results of the play and to answer the questions posed initially. Both quantitative factors taken from the computer records and qualitative ones introduced by the game participants are considered.

The status-of-forces file is organized into data sets—one data set per unit. There are six types of units in all: air units, surface-to-air missile units, combat-support units, ground units, logistic units, and supply units. From 16 to 22 parameters are used to describe each unit, depending on its type. For ground-combat units the variables describe such attributes as designation, location, activity, source of supplies, priority for supplies, total weight, strength, supply status, status of weapons, combat capability, etc. The terrain is never entered directly into the computer but is represented on topographic maps in the player rooms and the control room. Extracts of the terrain description such as trafficability factors are fed into the computer in connection with the conditions of engagement. Equipment characteristics include such factors as range, rate of fire, speed of movement over various types of terrain, lethality, and vulnerability. These items are not tabulated explicitly but are introduced as coefficients in the rules and formulas of which the assessment models consist.

The computation cycle takes perhaps an hour including punching, verifying and listing input cards, processing and updating the status-of-forces files, and printing the output on an off-line high-speed printer. The center computer, a Univac Scientific, is used for about 15 min. One cycle/day is played as a matter of routine and sometimes 2 or 3 cycles/day are played. Thus with 1 cycle representing a day of game time, the real time to game time ratio is at least unity. This is only an increase of three or four over THEATERSPIEL's less detailed manual predecessors. However it is estimated that if the present version of the game were to be played manually it would take at least 20 times as long as by machine because of the additional detail that has been added.

The computer code is currently being rewritten for an IBM 7040 computer.

American Management Association Games

A series of business games organized along much the same lines as the war game just discussed but not nearly so detailed has been developed for the American Management Association. The games are intended primarily for executive training. The first game of the series is well documented.[14] It treats a competitive situation of five companies producing and marketing a single product in a growing economy. The players attempt to allocate their cash funds so as both to obtain a large share of the market and increase total assets. The game is played with equal time intervals, each representing a calendar quarter. Twenty-five plays of the game were conducted in the fall and winter of 1956–1957.

Following an indoctrination period for the players the sequence of play assumes the pattern shown in Fig. 2. Initially and at the beginning of each subsequent time period the playing teams are given information concerning their own positions in the game. This includes such information as total sales in units and dollars, price of item, inventory level, actual and potential production rates, cost of production, share of market, past budget allocations, and

total working funds available for the current allocation. In addition the teams may be given general industry market information if they previously elected to purchase it. Altogether there are perhaps 12 to 15 items per team or 60 to 75 items for the five teams collectively.

The players allocate their cash funds among various activities: production, marketing, research and development, plant investment, and market research information. In addition they specify the unit price of the product for the next time period. Player decisions are required for about eight or nine items for each team during each time period. All allowable alternatives for the time period, five or ten per item, are listed on a form by the computer in advance. The players indicate their selections by circling the appropriate items on the form. These decisions are then entered into the computer by means of punch cards. The precise rules by which the computer evaluates the decisions are not known to the players. They are only given quantitative statements of a more or less obvious variety. The computer computes the attractiveness of each company's product as a simple function of marketing expenditures, research and development expenditures, and price. Each competitor's share of the market is based on the attractiveness of his product. The unit cost of production for each company is computed as a function of the production rate, the plant capacity, and the research and development expenditures. All formulas for computation are deterministic. The computer edits all output information and constructs a form to be given to each playing team each time period. The form gives a team its authorized information for the past time period and lists the possible choices of allocations for the next time period.

Usually 40 cycles are played, covering a 10-year period. The game is then terminated and a critique conducted. Control charts covering the history of the game are given out, and each team is asked to explain the strategy used and state what difficulties the group had experienced in its decision making. The computer requires about 2 min/cycle for evaluation. An entire play of 40 quarters including preplay indoctrination and critique can be conducted in 1 to 2 working days.

Other Digital Man-Machine Games

Digital man-machine games have been constructed covering a wide variety of subject matter. LP-1,[15,16] developed by the RAND Corporation Logistics Systems Laboratory, was a "man-machine simulation"—to use the developer's terminology—dealing with the management of 650 different replacement parts for aircraft; 30 items of information were carried for each part. The mechanized portions of the simulation were handled by an IBM 704 program consisting of about 25,000 instructions. The players made decisions on the basis of daily, monthly, and quarterly reports constructed for them by the computer. The game covered a period of about 3½ years and required 4 months of real time to play. The principal purpose of LP-1 was to evaluate a set of proposed supply policies and procedures.

Logistic games were also constructed by ORO and are in use at the Army Logistics Management Center.[17,18] Neither the RAND nor the ORO logistic models are properly "games" since the element of competition is lacking. However, they are often called games, and they are similar to games in that they involve human participants as players.

Not all digital man-machine games fall into the time-sequenced organizational pattern discussed earlier. For example, in an ORO experiment[19] on strategic gaming the players made bids for various territorial gains and allocated military forces to back up these bids. Close communication among the game participants and between the game participants and the machine was required for executing and recording the bidding process. The game was sequenced on a bid-by-bid basis with communication between the players and the machine being accomplished through on-line remote typewriters. In this example the computer not only performed the assessment and bookkeeping operations and presented results to the players, but also served as a communications system among all the game participants.

Another RAC man-machine war-gaming activity of an unconventional type was the assessment of the air operations and air defense portions of the 1961–1962 US Army War College War Games by a remotely located digital computer. The US Army War College War Games were essentially manual ones without a formal structure of time sequencing. The computer was used as an assessment aid on which were programmed the air operations and air defense calculations. These calculations were employed some hundreds of times during the games as the occasions arose. Communication with the computer was accomplished by means of an automatically encrypted off-line card-to-card data-transmission system connecting the gaming and computing areas, which were 100 miles apart. An average turnaround time for a set of assessments was $7\frac{1}{2}$ min. The mechanized assessment procedure made practical the use of a very detailed model, saved time for the game participants, and permitted the consideration of alternative strategies, an activity that had not been possible before.

The US Army Strategy and Tactics Analysis Group is developing a war game called CENTAUR.[20] It is notable in two respects: first, it is probably the most complete and comprehensive ground-warfare model ever attempted, and, second, it lies on the border between a machine simulation and a man-machine game, being a machine simulation with manual override. The computer is equipped with a display system presenting the state of the game. The simulation is automatically interrupted and the display updated every 15 min. On the basis of this display human commanders override, if desired, the decisions introduced at the beginning of the play.

A recent book[21] describes and classifies a representative set of 89 business games. Forty-three of these employ a computer in some capacity or other. Most of the games are very simple; however, a few are quite detailed. For example, the Carnegie Institute of Technology game used by graduate students in industrial management requires 100 to 300 decisions for each month of play, and 2 or 3 hr of playing time are required per month of game time. Between 30 and 50 months are usually played.

Another book[22] lists 95 different organizations engaged in either the play or the construction of business games, and a recent military survey[10] lists some 50 organizations engaged in or interested in war games of various types. Most of the war games are in the US but a few are in Britain and Canada. In addition some of the other NATO allies not covered in the survey employ digital man-machine games. All in all a conservative estimate of the number of digital man-machine games that have been developed and exploited is about 100. Some of these have been very-large-scale games.

CONTINUOUS VARIABLE MAN-MACHINE GAMES

A few man-machine games are based on models with continuous independent time variables and employ electronic analog computers. Such games are not numerous; however, they are novel and should not be overlooked.

Electronic analog computers[23] are devices for representing physical or conceptual systems by electrical networks. The networks are generally of the slowly varying dc variety with the variables of the system represented by voltages at various points. The most frequently used electronic analog computer is the electronic differential analyzer. A number of so-called "general-purpose electronic differential analyzers," capable of being set up for a variety of problems, have been produced. Special-purpose electronic analog computers also exist.

The principal element of the general-purpose electronic differential analyzer is the dc amplifier. By connecting it in an appropriate circuit with resistors and capacitors it may be made to behave as either an integrator, a summer, or an inverter. Other elements are fixed resistors for scale factors and constants, variable potentiometers for parameters, and special devices for multiplying or dividing two variables. Variable functions are introduced by mechanical or optical curve followers, photoelectric function generators, or tapped resistance-capacitance networks. Output is displayed on a galvanometer, written on a plotting table or tape recorder or converted to digital form, and displayed on a visual digital read-out device or punched into cards or tape.

Man-machine war games employing electronic differential analyzers use models in the form of systems of time-dependent differential equations—generalized Lanchester equations.[24] The equations usually relate rates of attrition, rates of ammunition expenditure, rates of resupply, etc., to allocation of effort. The allocations enter into the model as coefficients of the differential equations. These coefficients are set up on variable potentiometers under control of the players. Certain variables such as strengths of forces and phase lines are displayed to the players as the play proceeds. Each player observes the variables displayed to him and adjusts the potentiometers under his control accordingly.

Simple analog computer games are easy to set up and check. The computation can be performed very rapidly and the communication between the player and the machine is graphic and direct. On the other hand, as the model grows more complex the analog computer game requires more equipment. Games using a great deal of equipment become difficult to set up and check out. The analog computer is not suitable for bookkeeping operations; stochastic elements are difficult to introduce, complex logical decision processes cannot be handled easily, and the accuracy of the computation is limited. The general-purpose electronic differential analyzer may be changed from one problem to another by changing removable plugboards and resetting potentiometers so long as the problems are simple. However, for complex problems crosswiring between plugboards is required, and changing from one problem to another is a major operation.

HUTSPIEL

As an example of a continuous variable man-machine war game HUTSPIEL[25] is described, an analog computer game developed by ORO in 1955 for play on its Goodyear Electronic Differential Analyzer, the GEDA. HUTSPIEL is a theater-level war game directed to the study of the effects of various employments of tactical nuclear weapons and conventional air support on the defense of stabilized positions in Western Europe. The game was played by two persons, Red and Blue, one representing the NATO commander and the other the USSR theater commander. The situation played was one that might have occurred along the Rhine River in the summer of 1955. Initial conditions represented resources estimated to be available in event of an unexpected Soviet attack in the summer of 1955; full-scale values represented resources estimated to be available at the end of a 3-month buildup.

The combat area consisted of two Army group sectors, each with a frontage of about 150 miles containing front-line divisions aggregated to include tactical reserves, airfields, and forward supply depots. The Blue theater included the main NATO military supply system, transport facilities, and troops in France, Belgium, and West Germany. The Red theater contained the Soviet supply installations, transport lines, and troops committed west of the Oder-Neisse line. Troop reinforcements and materiel resupply from outside the theater were continuous throughout the play of the game.

The forces were symmetrical on the two sides as regards to type; however, numerical strengths and exchange rates differed. Each side employed ground forces, tactical aircraft, and nuclear weapons and used various installations including airfields, supply depots, and transportation. The combat forces were divided between effectives and ineffectives in each sector and between recuperable and reserve troops in the rear zones. Tactical aircraft were aggregated into a single type for all missions: nuclear weapons delivery, interception, conventional bombing, and ground-support operations. The aircraft themselves were considered to be either combat ready or deadlined. The aircraft sorties increased enemy casualties indirectly by disruption, disorganization, and neutralization.

The model distinguished between two types of supplies: petroleum products and ammunition. Supplies were transported, consumed, and destroyed throughout the game. Transportation was represented by two components—railroad rolling stock and rail net. The rolling stock was either damaged or undamaged, and the rail net undamaged, moderately damaged, or severely damaged. The play continued until either the ratio of ineffective to active troops in a sector reached an arbitrary value, or until active troop strengths in a sector were so reduced that the line could not be manned.

Player decisions consisted of allocations of troops among sectors and allocations of nuclear weapons and aircraft sorties among targets. Permissible targets were troops, airfields, depots, and transportation facilities in the sector and in the theater. Movement, except as this was involved in transporting supplies and troops by rail, was not represented in the game. Also omitted were the influences of weather and terrain intelligence gathering and dissemination, and the effects of damage to airfield runways and aircraft maintenance facilities.

The variables in the game were related by systems of ordinary differential equations. The equations were mostly linear; however, several multiplications, divisions, and time-dependent coefficients were used. All equations were deterministic, i.e., there were no stochastic elements. About 40 variables were represented on a side.

Special panels containing potentiometers and galvanometers were constructed to permit the players to read certain outputs and make allocations without their opponent's knowledge. Initially the game was permitted to run automatically on the computer until one of the players depressed his "hold" button to give him time to change his allocations. Later it was found more practical to run the game in discrete time increments with the computation for an increment starting when both players depressed their "ready" buttons. An increment was selected to be 1 day of game time. It was executed on the computer in 1 second. Generally two players could make a play of 60 to 90 days of game time in about ½ day of real time including indoctrination into the mechanics of the game. Through a series of plays with different players best strategies were determined by trial and error.

Other Continuous Variable Man-Machine Games

HUTSPIEL is the outgrowth of a series of simpler man-machine games developed at ORO for GEDA. These games considered such problems as the allocation of artillery fire among competing targets and the allocation of weapons in a two-sided missile exchange. Analog games have also been used by the RAND Corporation for studying the allocation of tactical air sorties. The development of the RAND and ORO continuous variable games has undergone a consistent pattern. As the games became more and more complex the equipment became saturated. The game designers were then faced with the alternatives of acquiring more equipment or recasting the game in a form suitable for a digital computer. The latter alternative has generally prevailed.

By far the largest continuous variable man-machine games have been those employed at the US Naval War College.[26,27] These games have been played on the Naval Electronic Warfare Simulator (NEWS) beginning in 1958 and are still being played. NEWS is a mammoth electronic differential analyzer. By means of dc amplifiers it computes continuously geographic coordinates of ships, aircraft, and other vehicles employed in the games. Amplifiers are also used to keep track of items such as ammunition supply and damage. A digital random-number generator is used with NEWS for introducing stochastic elements. Ten simulated command centers on each side are employed for communications between the players and the computer. These command centers are equipped with realistic output displays such as radar scopes and dead-reckoning tracers and contain input controls similar to those in naval-combat information centers. NEWS is used both for education at the US Naval War College and for evaluating plans by visiting commanders and their staffs.

OTHER TOPICS

In this section a number of topics that do not conveniently fall into any of the preceding sections are treated. To begin with, both hardware and software

are being developed in support of gaming, as in other areas of computer application. Hardware items include visual display systems suitable for presenting map-type information such as troop dispositions and aircraft tracks, special computer-control consoles permitting a player or controller to interrupt a computation to insert data or control information, and communications systems enabling game participants in different locations to communicate with one another. Much of the special-purpose equipment is similar to that being developed for other specialized applications such as military command-control systems.

Considerable software effort is being devoted to simulation languages[28,29,30] and preprogrammed general-purpose simulation formats.[31] These developments generally are designed to handle a broad class of simulations. However, several[32] are being tailored specifically for competitive military situations. The aim of such systems is to permit rapid preparation of large simulations. Additional work is being done on computer operating systems designed to facilitate the use of all special-purpose hardware and software features.

Systems of games are considered next. There is sometimes a requirement for a game to treat both the broad strategic aspects of an operation and the smaller tactical details. The broad considerations are required in the interest of completeness and the detailed ones in the interest of realism. To include both in one game tends to produce an unmanageable model. The situation has sometimes been handled by a system of games in which each game except the one on the highest strategic level takes its boundary conditions from the next highest game; and each game except the ones on the most detailed tactical level take their inputs from lower-level games.

ORO has experimented with such systems of games both for air defense and for ground warfare. In air defense the results of a detailed surface-to-air missile computer simulation were used as inputs to a theater-level air defense game with human commanders. A series of plays was successfully conducted. In ground warfare a system of three games, one each at the theater level, division level, and company level, was designed but never completely implemented.

The problems that arise in fitting together the various games of the system are more difficult than one might suppose. If the games are played simultaneously there is a coordination problem. The problem is aggravated by the fact that games on different levels are not conveniently played at the same real-time to game-time ratio. If the games are played successively, outputs of one game must be tabulated for later use as inputs to another. If lower-level games are played first the boundary conditions from the higher-level games are not known. If higher-level games are played first the inputs from the lower-level games are not known. This difficulty can be overcome by successive iterations; however, it is a sizable job.

Consider now the process of extracting information from games. In contrast to the mathematical theory of games, gaming consists of playing games, not solving them. A model is played through in time sequence with decisions introduced in any one of the several ways discussed earlier—formulated as rules or algorithms, prescheduled by means of a scenario, or introduced by human participants. If an optimum solution is desired it is hoped that a series of plays will enable it to be inferred.

The problem-solving ability of the gaming procedure might be improved on a makeshift basis by a single program permitting all three alternative ways of introducing decisions. Thus a scenario could introduce a series of decisions identical with those made by players in a previous play. A distribution of outcomes showing the effect of chance fluctuations could then be produced. Alternatively the scenario could be used to introduce decisions that were slight modifications of those made by players in a previous play. In this way one could search for improved solutions in the neighborhood of those employed by the players. The construction of algorithms yielding good results would also be facilitated by the ability to compare algorithmic solutions with those resulting from scenarios or player decisions.

A more direct way of improving the problem-solving ability of gaming would be to ask the computer rather than tell it what strategy to employ. The problem of introducing a strategy would be replaced then by the problem of stating player's goals or objectives in unambiguous terms. Techniques of heuristic problem solving would be needed.[33] At the present time they are being applied only to parlor games, puzzles, and simple mathematical problems. However, it is hoped that ultimately the techniques will help to solve real economic and military problems. It will not be possible to treat reality directly. A model will be needed. Games and simulations provide a broad spectrum of computerized models ranging from simple to complex and treating a variety of military and economic subjects. They might well serve as the first candidates for the practical application of advanced heuristic problem-solving techniques.

A heuristic feature that might be useful even in the absence of a complete problem-solving program would be a procedure enabling a player to look ahead several stages on the decision tree of possible game moves. This technique has already been employed in the construction of programs to play chess or checkers.[34] One may regard a game as a set of time-dependent variables. At any instant the variables assume particular values that collectively describe the state of the game. Given the current state the set of all possible future states takes the form of a tree with the number of branches increasing exponentially at each stage as in Fig. 3. The state actually obtained at any stage depends on the decisions of the players and on chance happenings at the previous stage.

In man-machine gaming a player would be given the facility for tracing his way through the tree based on assumed moves for him and his opponents. His actual move would then be based on his evaluation of the worth of the various alternative states that might result.

Needless to say, complete exhaustion of all branches of the decision tree in this manner is impossible. Even in a game as simple as checkers the number of branches is so great that it is beyond the capability of any computer technology that can be foreseen. Nevertheless a selective look-ahead procedure based on expected values if necessary could be of considerable use.

Finally, realism is considered. In a game designed to explore current real-world problems one would like so far as possible to use real-world data—real friendly capabilities based on up-to-date reporting, real competitor's capabilities based on best intelligence estimates, and a real environment based on research and experiment. Thus the game would resemble a military command

control system or a business-management information system. The difference between the two would be that the game decisions affect only the variables in the model—not the real world.

The ultimate in realism would be a system in which the decision maker could not distinguish game data from real-world data, nor tell whether his decisions were being implemented only in the game or in the real world itself. In this case if both the game and the world were asked the same question would

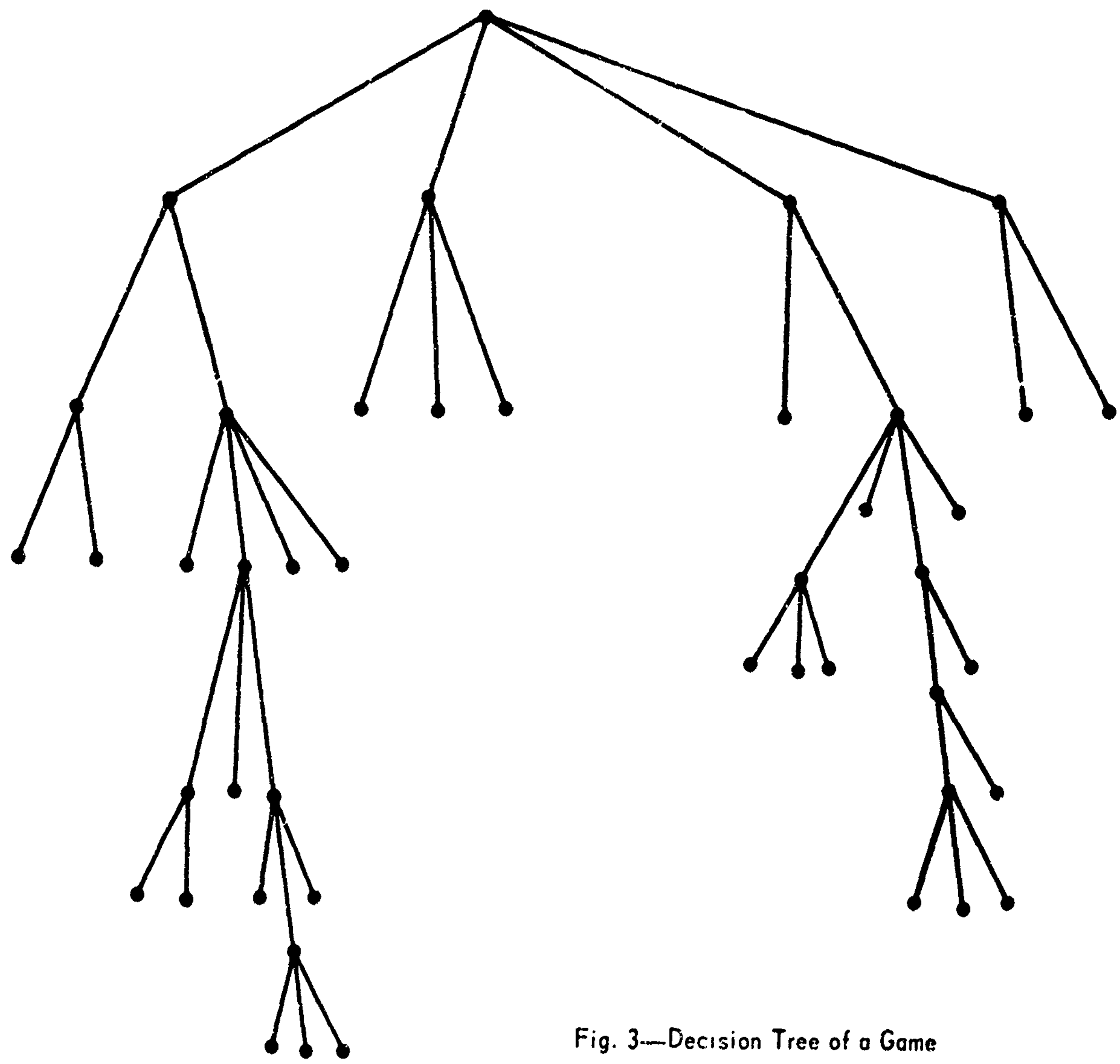

Fig. 3—Decision Tree of a Game

they give the same answer? Probably not. In common with other analytic predictive mechanisms the most that the game can do is define the universe of possible states depending on the choices of competitors and chance. The real world selects a particular sample of one.

In concluding the paper it should be noted that the usefulness of gaming in some of its roles is controversial. A paper on this subject by Deemer and

Thomas[35] won the Lanchester prize for the best paper in operations research in 1957. Gaming appears to be rather well accepted as a technique of group synthesis, as a means of qualitative analysis of gross effects, and as a method of instruction. However, its use as a means of achieving valid quantitative solutions to operational problems is frequently questioned. Critics of the technique point to the nonreproducibility of player decisions, the large size of the sample of plays required, the difficulties in obtaining data, and the problem of verification of the gaming model. Furthermore they hold that the impressive environment including teams of high-level people, large-scale computers, and elaborate display and communications systems tend to make the appearance of validity so striking that the actual lack of validity passes unnoticed. Defenders of gaming consider these criticisms exaggerated and ask what alternative techniques exist for analyzing complicated competitive problems involving both materiel and human elements. Regardless of the controversy the use of gaming is widespread at the present time and appears to be expanding.

Accepting gaming for what it is, let us review what computers can do for it. There are two substantive contributions—an increase in the speed of play and an increase in the level of detail that can be accommodated.

Contrary to general belief the increase in speed of play is not great—a factor of 3 or 4 over less detailed manual versions is perhaps typical. To do better than this is generally impossible so long as the human decision makers are retained.

So far as detail goes it must be recognized that in many situations the level of detail possible is limited not by computer capacity but by available data. Detail is difficult to estimate. Some kind of a measure is needed. The one most frequently used is the number of computer instructions. This is not really satisfactory since it depends on the particular machine, the skill of the programmer, and the amount of machine housekeeping that is done. Moreover this measure is not in the proper form for measuring the level of detail of a manual game.

Another approach is to measure the amount of information involved. Game information is of two types—fixed and variable. Fixed information is used principally to describe environment. Both manual and machine games reference great quantities for it. So long as fixed information is expressed in a form suitable for human consumption—tables, graphs, and topographic maps—humans compete rather favorably with machines.

The other type of information is variable data used to describe the state of the game. In a highly developed manual game there may be on the order of 100 state variables on each of two sides. If each variable is significant to 3 percent of its maximum value it can be represented by 5 bits and the state of the game by 1000 bits. By comparison THEATERSPIEL uses 150 to 200 bits per unit and hence requires approximately 100,000 bits for a maximum size play of 275 units on each side. HUTSPIEL has 40 variables on a side represented in continuous variable form. At 5 percent accuracy this amounts to about 300 bits, the equivalent of a medium-sized manual game. CARMONETTE uses about 2500 36-bit words or 90,000 bits in all. Newer games and simulations now being developed use many hundreds of thousands of bits to describe a state—several orders of magnitude more than manual games.

To recapitulate, the advantages of using a computer in gaming are as follows: First the computer provides a number of services of convenience—uniform refereeing, elimination of bookkeeping and computational errors, automatic recording and editing of intermediate and final results, and relief from computational drudgery. Second the computer permits an increase in speed. So long as human participants introduce decisions at approximately the same rate as if the computer were not used, this increase is limited to a relatively modest factor, perhaps 5. Third, the computer permits an increase in detail by a large factor, perhaps by as much as 100 to 1000.

One pays for these advantages by accepting the costs—a programming effort that is expensive both in terms of lead time and man-hours, the sacrifice of a certain amount of flexibility, and the necessity for computer availability on a priority basis.

Appendix A

GUIDE TO THE LITERATURE*

The literature on gaming is scattered. Some articles are published in professional journals, others are included in the proceedings of conferences and symposia, and still others are issued as separate reports. Also some literature on war gaming bears a military security classification and is therefore on limited distribution.

Fortunately for the newcomer there are a number of bibliographies to help introduce him to the field. The principal ones are listed in Sec I below. Conference and symposium proceedings that treat gaming and simulation are listed in Sec II. A selection of papers appearing subsequent to the period covered by the Bibliographies is given in Sec III.

No attempt has been made to make the listing in Sec III complete; in fact the scope of this section has been deliberately limited. Items appearing in the list of specific references in the body of this chapter have not been repeated except in several instances where it was desirable to introduce annotations. Abstracts appearing in the Bulletin of the Operations Research Society of America have not been referenced individually, nor have papers appearing in conference and symposia proceedings been generally so referenced. The extensive literature on the mathematical theory of games is omitted. Simulation is covered only when used in a somewhat narrow sense relating to gaming. On the other hand the reference list on Lanchester's Equations (item 16 below) is included since it is, so far as is known, the only reference list of its kind and since Lanchester's Equations bear a close relation to many of the models used in war gaming. Military publications have been listed only when they are unclassified. Although necessary this is a very severe limitation. The identification number beginning with the letters AD, appearing in some of the entries, refers to the serial number of the document at the Defense Documentation Center (DDC), formerly the Armed Services Technical Information Agency (ASTIA).

The literature on gaming and simulation may be followed on a continuing basis in the two periodical reviews listed in Sec IV.

*Completed 2 July 1963.

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1. Acer, John Whedon. Business Games: A Simulation Technique. (Information Series 3) Bureau of Labor and Management, State University of Iowa, 1960. Bibliography: p. 42-48.

2. Air Force Systems Command, Aeronautical Systems Division. A Survey of Mathematical and Simulation Models as Applied to Weapon System Evaluation. R. E. Cline, Institute of Science and Technology, University of Michigan. ASD Tech Report 61-276. October 1961. 148 p. AD 269 235.

   Based on questionnaire, visits and a general conference. Major emphasis devoted to the interests of the Air Force. Contains 56 detailed abstracts of models, including war game models. Appendix C: Abstracts, pages 18-132. Each abstract followed by a list of publications. There is a subject guide to the abstracts.

3. Army, Strategy and Tactics Analysis Group. Directory of Organizations and Activities Engaged or Interested in War Gaming. (Cumulative) Bethesda, Maryland; (1962). 130 p.

   Survey based on a questionnaire distributed by STAG in December 1961. Divided into two sections: 1) organizations engaged in war gaming and 2) organizations interested in war gaming. Each section consists of summary sheets and detailed descriptions. The descriptions cover past, present, and future effort; and a list of publications. Emphasis on Army activities. Change 1 issued 25 March 1963.

4. Batchelor, James H. Operations Research: An Annotated Bibliography. 3 vols. St. Louis Univ Press, 1959, 1962, 1963.

   Index with analytical entries for games, gaming, game theory, and simulation. Coverage to 1961.

5. Cohen, Kalman J., and Eric Rhenman. "The Role of Management Games in Education and Research." Management Science, Vol 7 (1961). p. 131-166.

   Reviews 100 business games developed in the U.S. and in Europe. Coverage includes the game as a research tool in the social sciences.

6. Cragin, S. W., Jr., et al. Simulation: Management's Laboratory. Simulation Associates, P.O. Box 55, Bradford, Mass.; April 1959. 118 p.

   A student report prepared at Harvard Graduate School of Business Administration. Appendix B provides a glossary of terms associated with the simulation literature. Appendix C is a listing of 204 articles, papers, and books on simulation; divided into: 1) theory, 2) industrial applications, 3) military applications, and 4) related material. This bibliography represents an attempt at completeness; references range from elementary to advanced.

7. Deacon, A. R. L. "Selected Bibliography; Books, Articles, and Papers on Simulation, Gaming and Related Topics." (In Simulation and Gaming: A Symposium,

American Management Association Management Report 55, The Association, 1961.) p. 113–131.

Covers period from 1955–1960 with a few earlier references. Divided into the following categories: 1) industrial simulation, 2) military simulation, 3) industrial games and gaming, 4) military gaming, 5) game theory, and 6) related research and reading. Bibliography contains over 300 references.

8. General Electric Company. Simulation: An Annotated Bibliography. 2 vols. Information Systems Operation-Defense Systems Department, Washington, D. C.; July 1962.

   Volume 1 (170 p.) is an annotated compilation of 238 papers, documents, programs, and brochures issued by GE; and arranged by 48 broad subject classifications. Volume 2 (86 p.) lists citations for 347 papers, documents (classified and unclassified), and articles issued by sources other than GE. This volume is not annotated. Documents are listed by author and source (when no author); there is an index by source and GE accession number. Most of the documents appearing in this bibliography are available from the Defense Documentation Center (DDC).

9. Greenlaw, Paul S., et al. Business Simulation in Industrial and University Education. Prentice-Hall, 1962. 408 p. Bibliography: p. 342–349.

   The book presents the historical development of business games in this country and a survey of the more important ones. The terms "simulation" and "business games" are used interchangeably. Characteristics of each entry are in outline form: source of information, references if any, and a paragraph of comments. There is a selected bibliography of 141 references.

10. Kibbee, Joel M., et al. Management Games; A New Technique for Executive Development. (Reinhold Management Reference Series) Reinhold, 1961. Bibliography: p. 337–343.

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11. Malcolm, D G. "Bibliography on the Use of Simulation in Management Analysis." Operations Research, Vol 8 (1960). p. 169–177.

    The paper lists 167 items in all. These are divided into the following sections: 1) industrial simulation, 2) military simulation, 3) industrial games, and 4) military games.

12. Morgenthaler, George W. "The Theory and Application of Simulation in Operations Research." (In Progress in Operations Research, Russell Ackoff, Ed., ORSA 5, Wiley, 1961.) p. 363–419. Bibliography: p. 413–419.

    Bibliography contains 117 references.

13. Naval War College. Fundamentals of War Gaming. 2nd edition. Newport, Rhode Island; November 1961.

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14. Operations Research Office.* Bibliography on War Gaming. Vera Riley and John P. Young. ORO-BRS-7. 1957. 94 p.

    An annotated bibliography divided into two parts: Early War Games and Modern War Games. Within the Early War Games, a distinction has been made between the "Rigid" Kriegsspiel types and the "Free" Kriegsspiel types, and all references are arranged chronologically. The section on Modern War Games has been sub-

*Now the Research Analysis Corporation.

divided into: 1) theoretical games, 2) military games, and 3) economic and industrial gaming.

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16. _____. Lanchester Equations: Unclassified Publications. Library Reference List 7A. July 1962. 9 p.

Annotated listing of applications and extensions of the square and linear laws; arranged chronologically

17. Shubik, Martin. "Bibliography on Simulation, Gaming, Artificial Intelligence and Allied Topics." Journal of the American Statistical Association, Vol 55 (1960). p. 736–751.

The references fall under the following divisions: 1) simulation, 2) gaming and allied topics, 3) Monte Carlo, and 4) systems.

18. Technical Operations, Inc. Joint War Gaming Feasibility Study. Prepared for the Defense Atomic Support Agency, contr: DA-49-146-XZ-077. Washington, D. C.; April 1961. 97 p.

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Appendix covers gaming activities of U. S. Army War College, U. S. Army Electronic Proving Ground, Ballistic Research Laboratories, CAORE (Canadian Army Operational Research Establishment), CONARC (U. S. Continental Army Command), U. S. Naval War College, Operations Research Office, and the RAND Corporation.

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21. U. S. Department of Commerce, Office of Technical Services. Keywords Index to U. S. Government Technical Reports. (Permuted Title Index) Vol 1 (1962), --. Washington, D. C. Government Printing Office.

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Contains a number of papers on gaming and simulation.

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Proceedings of a conference sponsored by the International Federation of Operational Research Societies. Papers are either in French or English with translated

abstracts at the end. Contains 8 papers classified by the editors as simulations and a summary of a discussion session on problems in the use of simulation.

24. National Simulation Conference, Proceedings. Southern Methodist University, 1956. 210 p.

The thirty-five papers presented cover the use of analog and digital computers in simulations.

25. System Simulation Symposium, Report of. N. Y., AIIE, 1958. 106 p.

Proceedings of a symposium sponsored by the American Institute of Industrial Engineers, The Institute of Management Sciences, and The Operations Research Society of America. There were seventeen papers presented by people engaged in industrial and military simulation activities.

26. Report of the Second System Simulation Symposium. N. Y., AIIE, 1960. 67 p.

The second symposium was a "workshop symposium" and the four papers presented are a part of the report. Papers: "Simulation and Stimulation," R. Bellman; "The Use of Simulation in Management Analysis," D. G. Malcolm; "Simulation for Problem Solving," D. B. Hertz; and "Simulation for Business Training," T. E. Caywood.

27. War Gaming Symposium, 1961, Proceedings. (Available for $2.00 from J. L. Overholt, 4641 North 24th Street, Arlington 7, Va.)

Proceedings of a symposium sponsored by the Washington Operations Research Council. There were eight papers presented concerning the planning, design, playing, and analysis of both manual and machine games.

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36. David, Edward E., Jr. "Digital Simulation in Research on Human Communication." Proceedings of the IRE, Vol 49 (1961). p. 319-329.

37. Dill, W. R., et al. "Experiences with a Complex Management Game." California Management Review, Vol III (1961). p. 38-51. (Abstract: International Abstracts in Operations Research, Vol 1, No. 143, p. 80.)

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